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Infrared spectrum of bromodiborane and attempted preparation of chlorodiborane for infrared study.

Patterson, Lee Roy.

Monterey, California: U.S. Naval Postgraduate School

http://hdl.handle.net/10945/12344

INFRARED SPECTRUM OF BROMODIBORANE
AND ATTEMPTED PREPARATION OF
CHLORODIBORANE FOR INFRARED STUDY

LEE ROY PATTERSON

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FOR INFRARED STUDY

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Lee Roy Patterson

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AND ATTEMPTED PREPARATION OF CHLORODIBORANE

FOR INFRARED STUDY

by

Lee Roy Patterson

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
CHEMISTRY

United States Naval Postgraduate School
Monterey, California

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AND ATTEMPTED PREPARATION OF CHLORODIBORANE

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This work is accepted as fulfilling

the thesis requirements for the degree of

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from the

United States Naval Postgraduate School

ABSTRACT

Bromodiborane, B_2H_5Br, was prepared by mixing bromine and diborane. The resulting unstable B_2H_5Br was separated from its equilibrium mixture by standard fractionation techniques in a high vacuum system. The infrared spectrum in the 4000 to 250 cm^{-1} region was obtained for B_2H_5Br in both the gaseous state and as a frozen solid film. Frequency assignments were made by correlation with B_2H_5D and $B_2H_5CH_3$ assignments.

The preparation of chlorodiborane, B_2H_5Cl, was attempted by mixing BCl_3 and B_2H_6. All attempts to separate B_2H_5Cl from its equilibrium mixture were unsuccessful as were all attempts to observe its formation by absorption spectrum of the gas mixture.

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I. INTRODUCTION

The vibrational spectra of B_2H_6 and B_2D_6 are well understood and relatively little doubt remains regarding assignments of fundamentals.[1-4] The effects on the vibrational spectrum of diborane when deuterium is substituted for one of the terminal protium atoms [5] and the effects of CH_3- and C_2H_5- groups substituted on diborane [6] have led to the assignment of some bands believed to be caused by the $-B_2H_5$ fragment.[6] The examination of spectra of the halodiboranes (B_2H_5Cl and B_2H_5Br) would be a further check on the assignments given for the $-B_2H_5$ fragment and should assist ultimately in elucidating structures of more complex boron hydrides.

II. EXPERIMENTAL METHODS

1. Preparation of diborane.

Preparation of a monohalogen-substituted diborane requires the preparation of the intermediate, diborane, itself. The procedure first used for producing diborane was that suggested by R. Turner. /7/ Six grams of powdered potassium borohydride, KBH_4, (97% pure obtained from Metal Hydrides Company, Beverly, Mass.) were placed in a 500 milliliter three necked flask equipped with a magnetic stirrer. (Fig. 1) Through one neck passed dried hydrogen gas. The gases evolved were emitted through another neck. Through the third neck, 4N H_2SO_4 was allowed to drop onto the powdered KBH_4. The reaction was quite vigorous and was essentially complete after the addition of about 40 ml of acid, but 250 ml in all were added to insure completion. The gases given off were passed through a dry ice cooled trap and then a liquid air cooled trap where the product was collected. The non-condensed gases were allowed to pass through a mercury bubbler under a hood.

During thirteen such processes in which the acid dropping rate, the stirring rate, the sweeping gas rate and the temperature of the reaction were all varied, the yield of pure B_2H_6 as established by infrared spectrum never exceeded three percent. Along with the poor yield there was generally a high contamination due to CO_2 in the product gases. In fact, the percent contamination rose irregularly with each experiment. All evidence pointed to the KBH_4 actually containing some carbonate as an impurity. The KBH_4 evidently absorbed
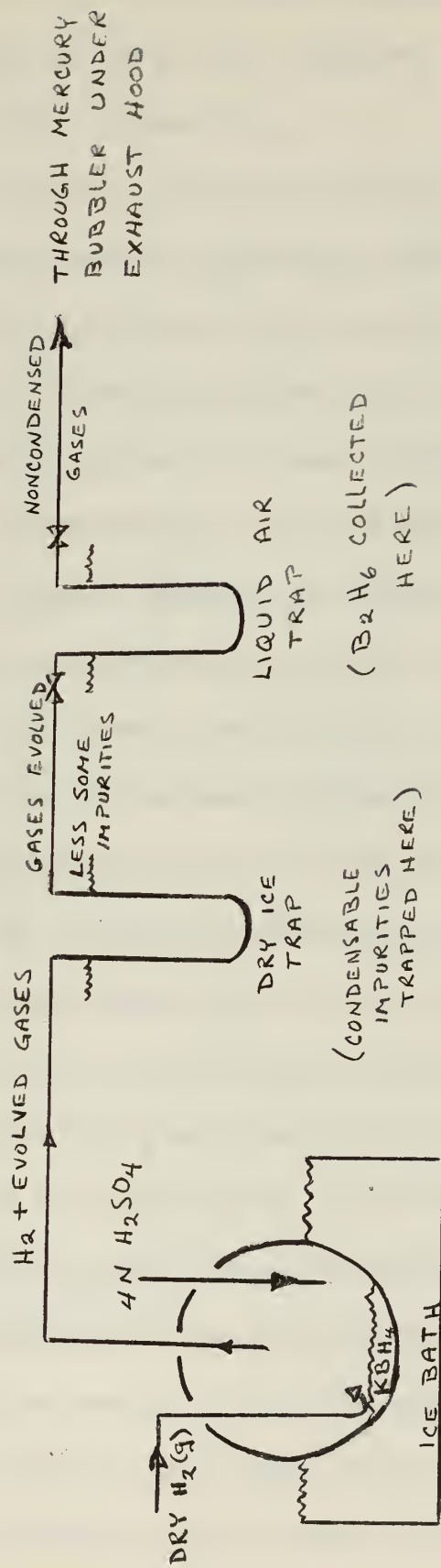
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Fig. 1. Initial Method of Producing B_2H_6

4N H_2SO_4 Added to Solid KBH_4

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CO_2 and moisture from the air each time the KBH_4 container was opened, and the borohydride reacted to form a carbonate. The carbonate in turn reacted with the acid to liberate CO_2.

In analyzing the poor yield for the reaction, it was decided that the highly exothermic reaction caused much steam to form from the 4N acid, and this steam hydrolyzed the B_2H_6 rapidly to form $B(OH)_3 + H_2$. No matter how slow the reaction, or how cool, the hydrolysis destroyed the majority of the B_2H_6 formed. The only modification to the reaction that could solve the problem was to use concentrated H_2SO_4 and eliminate the water; however, dropping concentrated H_2SO_4 onto solid KBH_4 -- even in an inert atmosphere of helium -- was far too vigorous a reaction to be safely done in the laboratory. The concentrated acid plus borohydride approach had been published /8/ though with the recommended modification that the solid KBH_4 be added slowly and in small amounts to the concentrated sulfuric acid instead of vice versa.

Since the original yields were so low, a switch was made to the new procedure of adding the solid KBH_4 to the acid. Two hundred milliliters of concentrated H_2SO_4 were placed into a 500 ml three necked flask equipped with a magnetic stirrer. (Fig. 2) One neck still contained the sweeping gas inlet, but the sweeping gas now utilized was dried helium. The second neck was attached to a cold finger condenser containing dry ice and acetone. The product gases passed by the cold finger condenser through a trap at about $-130^\circ C$ (ligroin at its melting point) and were collected in a trap at liquid air temperature. Any
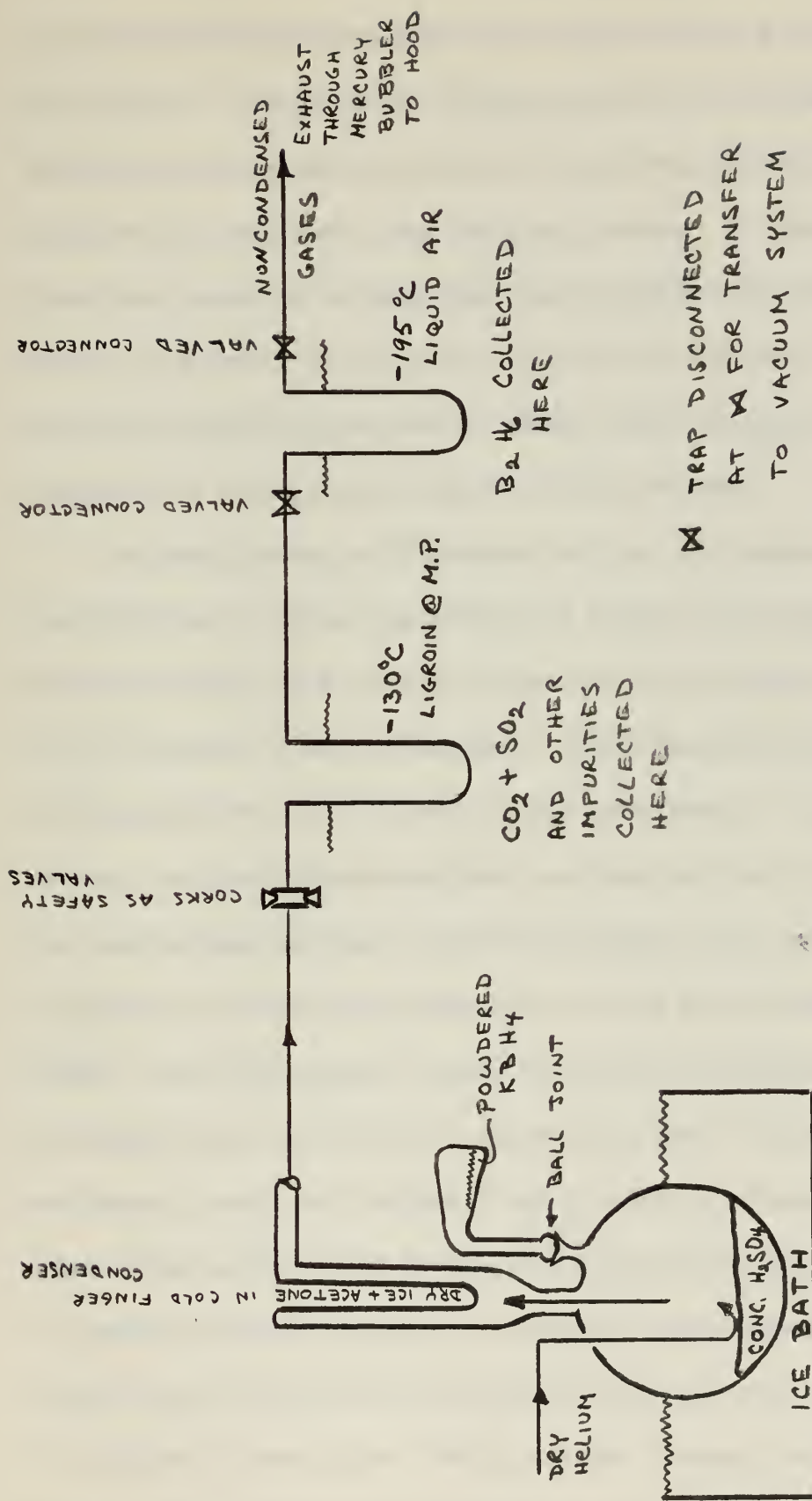
4

Fig. 2. Primary Method of Producing B_2H_6

Solid KBH_4 Added to Concentrated H_2SO_4

noncondensable gases were allowed to pass through a mercury bubbler into a hood. The cold finger condenser plus the -130°C trap were fairly effective in eliminating the previous CO_2 contamination, but small amounts still persisted in the collected product. To the third neck of the flask was connected an Erlenmyer flask equipped with a tube at right angle to the flask. The tube was connected to the neck of the reaction flask via a ball joint and socket. Seven grams of KBH_4 powder and a magnetic rod were placed inside the Erlenmyer flask.

By manipulating the Erlenmyer flask via the freedom of the ball joint while at the same time moving the magnet in the powder, small amounts of KBH_4 were allowed to drop into the acid (which was cooled by an ice bath to slow the reaction). While the control of the rate of solid addition was not too good, it was satisfactory. In spite of the cooling, stirring, inert atmosphere, and slow addition of reactant, the reaction was extremely vigorous with some small amount of burning, or flashing, accompanying production of many fine particles of free sulfur. The sulfur rapidly covered the inside of the reaction flask and prevented visual observation of the reaction rate. The whole system was under a pressure of helium of about five psig. The decision as to when to add another small portion of solid could be made by watching the pressure gauge fluctuate as the product gases were evolved. The reaction was so rapid that the pressure often rose three to four psi upon the addition of some solid. During several of these preparations of B_2H_6, the pressure rose on the system sufficiently to blow out some

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corks installed in the outlet line as safety valves. The addition of solid KBH_4 to concentrated H_2SO_4 consistently gave yields of about 50% B_2H_6, and this method was utilized for the preparation of all the B_2H_6 used thereafter.

The B_2H_6 that was collected in the liquid air cooled trap contained the impurities SO_2 and CO_2 in large quantities. The B_2H_6 was purified by repeated fractional crystallizations in a vacuum system. This process was accomplished by detaching the liquid air cooled collecting trap from the preparation system as shown in Fig. 1 and reconnecting the still frozen trap to the vacuum system. Once the trap was integral to the vacuum system, the product gas, B_2H_6, was separated by repeatedly passing the gas mixture through traps at $-76^{\circ}C$, $-95^{\circ}C$, $-130^{\circ}C$ and $-195^{\circ}C$. The B_2H_6 was collected in the $-195^{\circ}C$ trap as condensed vapor out of the -130°trap.

2. Attempted preparation of chlorodiborane.

Once an ample supply of B_2H_6 was available, attempts to produce B_2H_5Cl were commenced. The chosen approach to preparing B_2H_5Cl was essentially that of Schlesinger and Burg /9/ in which freshly prepared B_2H_6 is placed into a container containing BCl_3 in near stoichiometric amounts according to: $5B_2H_6 + 2 BCl_3 = 6 B_2H_5 Cl$. Since Schlesinger and Burg /10/ reported an equilibrium situation and fairly rapid kinetics such that it is nearly impossible to separate pure $B_2H_5 Cl$, the plan was to place the B_2H_6 and BCl_3 into a standard IR gas cell and follow the process of the equilibrium and the formation of B_2H_5Cl by observing

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the absorption spectrum of the gas mixture. Resolution of the B_2H_5Cl was to be accomplished by external compensation for the B_2H_6 present in the mixture.

In the first attempt, about 70 mm[1] of BCl_3 (obtained from Matheson Co., Inc., Newark, Calif.) along with 50 mm of B_2H_6 were placed into a ten centimeter long pyrex glass IR gas cell and periodic spectra were taken to observe the reaction. Three new characteristic absorption peaks (3200, 1460, and 1360 Cm^{-1}) were found; however, upon evacuation of the cell, these peaks persisted on the inner surface of the NaCl windows of the cell. One hundred millimeters of BCl_3 were placed into the cell by itself and the 3200 and 1460 Cm^{-1} peaks were observed to decrease in intensity while the 1360 Cm^{-1} peak increased. Furthermore, upon evacuation of the cell and then filling with 50 mm B_2H_6 the opposite occurred -- the 3200 and 1460 Cm^{-1} peaks increased as the 1360 peak decreased. Upon dismantling the empty IR cell, there was observed what appeared to be a reaction product from the beeswax and resin used to hold the NaCl windows in place on the glass cell.

To get away from the beeswax and resin interaction with the reactants, the whole process was tried again utilizing IR-tran windows and neoprene "O" rings as seals. The results were quite similar to the time before, only this time the "O" rings were being attacked instead of the wax and resin.

[1]All gas quantities are referred to by the pressure in the vessel considered in units of millimeters of mercury at room temperature. Usual vessel size was about 500 ml.

The idea of trying to watch the reaction as it took place in an IR cell was abandoned. It was decided to place the reactants into a 500 ml pyrex bulb sealed with a stopcock using relatively non-reactive Kel-F grease. The intention was to periodically transfer the contents of the reaction bulb to an IR cell for a few minutes and then transfer the gases back and hope that the time within the IR cell would be insufficient for the surface reaction previously observed to take place. Accordingly, 20 mm B_2H_6 and 30 mm BCl_3 were placed into the bulb. The bulb was placed in a 0^OC bath for three hours to hold the BCl_3 in liquid form. After the three hours, the bulb pressure had increased from 50 mm to 68 mm, and the IR spectrum showed some HCl formed and some decrease of B_2H_6. Also, 13 mm of the 68 mm total were noncondensable at liquid air temperatures -- presumed hydrogen. Then the amount of each reactant in the bulb was increased to 110 mm B_2H_6 and 122 mm BCl_3, and the 0^OC bath was repeated for four hours. This time there was a pressure increase to 350 mm, and 160 mm of noncondensable (in liquid air) gas was formed. There was some white solid formed in the vicinity of the region occupied by the liquid BCl_3 (when at 0^OC). Again the IR spectrum showed a decrease in both reactants, but the only observable product in the spectrum was HCl. Of course, there was also the H_2 gas and the solid formed. An IR spectrum of the solid showed it to be predominantly $B(OH)_3$. This would indicate that moisture managed to leak into the bulb and hydrolyze the B_2H_6 accounting for the decrease in B_2H_6 concentration. It was decided to try one more attempt to

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produce an equilibrium mixture of B_2H_5Cl, but this time there was
added to the old mixture (now mostly HCl in the bulb at a pressure of
190 mm) another 66 mm of BCl_3 and 90 mm of B_2H_6. Then the bulb was
subjected to a $70^\circ C$ warm bath for six hours, and the mixture was
checked by IR spectrum. There was some small decrease in both BCl_3
and B_2H_6 concentrations and 40 mm of noncondensable (presumed hydro-
gen) were formed; however, no new product was noticeable in the spec-
trum. Then the bulb with its gaseous mixture of about 50 mm BCl_3,
75 mm B_2H_6 and 200 mm HCl was placed into another $0^\circ C$ cold bath.
After four hours of cold bath treatment, the gas mixture was again
placed into an IR cell for a spectrum reading. The spectrum again
showed a decrease in both B_2H_6 and BCl_3 with a small increase in
HCl. No new peaks were noticeable. In all the attempts to produce
B_2H_5Cl, an IR spectrum was used to "isolate" the B_2H_5Cl, and evi-
dently if any B_2H_5Cl was produced it was in such small quantity
relative to the B_2H_6 present that its absorption spectrum was over-
shadowed by that of the B_2H_6.

An attempt was also made to use vapor phase chromotography
(GLPC) to detect any new component, but no one column was found
that would detect B_2H_6, BCl_3 and HCl at one time. The most nearly
successful GLPC column was a 55 cm by 0.6 cm diameter tubing packed
with 30 - 60 mesh firebrick with mineral oil as the adsorbing agent. /11/
With this column operating at room temperature and 2.5 PSI, B_2H_6 was
detected at an elapsed time of about 20 seconds. One GLPC run on

the final B_2H_6, BCl_3, HCl mixture detected a two percent yield of unknown gas (percentage based on B_2H_6 plus unknown equal 100) at an elapsed time of about 25 seconds, or just after the B_2H_6. This unknown gas was definitely not HCl or BCl_3 which were not detected within any reasonable time by the column. Whether this two percent was the elusive B_2H_5Cl was impossible to tell since the quantity was too small to collect to analyze by IR or chemical means. It was decided to abandon the attempt to produce B_2H_5Cl in favor of producing the more stable B_2H_5Br.

3.   Preparation of bromodiborane.

The planned method of preparing B_2H_5Br was that specified by Stock /9/ in which B_2H_6 and either HBr or Br_2 are heated together for about two hours until the substitution is complete. In the case of the B_2H_5Br though, the compound is stable enough and sufficiently different in vapor pressure to allow separation from its equilibrium mixture -- believed to be: /9,10/

$$6B_2H_6 + 6Br_2 \longrightarrow 6B_2H_5Br + 6HBr \rightleftharpoons 5B_2H_6 + 2BBr_3 + 6Hbr$$
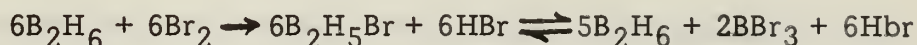
In the first attempt to produce B_2H_5Br, the method of warming equal volumes of HBr and B_2H_6 at 90°C for two hours was chosen. /9/ Approximately 100 mm each of freshly prepared B_2H_6 and the middle fraction of some commercially bottled HBr were placed in a 500 milliliter glass bulb. This bulb was placed into a hot bath for two hours, and then the contents were transferred to an IR cell for a spectrum. There was no noticeable change in the gas mixture except that two

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millimeters pressure of noncondensable gas was formed. After trans-
ferring the gases back to the bulb, the bulb was heated at $90^{\circ}C$ for
another four hours. This time there was a reaction. However, it
appeared that the major reaction was the result of heat causing the
grease on the bulb's stopcock to thin sufficiently to allow air and
water vapor to enter, since there was a deposit of white solid left on
the inside of the bulb that later proved to be $B(OH)_3$ according to an
IR spectrum. There was also 96 mm of noncondensable gas that
probably consisted of air plus H_2 from the reaction $B_2H_6 + 6H_2O =$
$2B(OH)_3 + 6H_2$.

For the second attempt to produce B_2H_5Br, the method chosen
was the alternate method recommended by Stock /9/ in which a one
third stoichiometric amount of Br_2 is added to B_2H_6 and heated at
$100^{\circ}C$ till the Br_2 color disappears. The reaction being $B_2H_6 +$
$Br_2 \rightarrow B_2H_5Br + HBr$. Accordingly, 180 mm of B_2H_6 were placed into
a 500 ml glass bulb equipped with a well greased stopcock, and then
61 mm pressure of Br_2 was added. Once again there was moisture con-
tamination, but this time the stopcock was tight, and the moisture prob-
ably entered in accompaniment with the bromine. The Br_2 vapor had
been taken off of some liquid bromine via a vacuum system at room
temperature without any fractionating. Evidently there was enough
moisture present in the liquid bromine to be transferred over at room
temperature with the bromine vapor. Anyway, the now familiar result

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of hydrolyzed B_2H_6 yielding the white solid $B(OH)_3$ plus hydrogen was observed.

After cleaning the 500 ml reaction bulb for another try at producing B_2H_5Br, 284 mm pressure of B_2H_6 was placed into the bulb along with 72 mm of carefully fractionated bromine vapor. Taking special pre-cautions to insulate the stopcock from the heat of the $100^{\circ}C$ bath, the mixture was heated for thirty minutes at which time the bromine color had disappeared. After transferring the gases from the reaction bulb to the vacuum system, it was found that about 30 mm of hydrogen had been formed. Fractionation of the remaining gases resulted in 10 mm pressure being isolated between temperatures of $-130^{\circ}C$ and $-30^{\circ}C$. An IR spectrum of this 10 mm pressure in a 500 ml volume resulted in a logical spectrum for B_2H_5Br. No HBr appeared in the spectrum con-taining B_2H_5Br, but HBr was found in the fraction between $-190^{\circ}C$ and $-130^{\circ}C$ confirming a substitute reaction and effective fractional separa-tion. To confirm the identity of B_2H_5Br, a vapor pressure reading was desired, and therefore more product was required. The original 10 mm of B_2H_5Br was frozen in liquid air, and the remaining gases from the original mixture were allowed to come to equilibrium again in the 500 ml reaction bulb. This time no heat was applied, the reaction bulb re-maining at room temperature. Twenty four hours later, another ten millimeters pressure of B_2H_5Br in a volume of 500 ml was collected from the equilibrium mixture by fractional condensations on the vacuum system between baths of $-130^{\circ}C$ and $-30^{\circ}C$. An IR spectrum of this

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fraction was identical with the previous sample. This product was frozen with the previous sample and saved in an evacuated tube kept at liquid air temperature. Still the total amount of B_2H_5Br collected was insufficient to obtain a positive vapor pressure and confirm the sample as monobromodiborane. Consequently, another 115 mm pressure of carefully fractionated bromine plus 110 mm pressure of diborane was added to the previous equilibrium mixture in the 500 milliliter pyrex reaction bulb. A trace of bromine color persisted in the flask even after 48 hours at room temperatures, but heating the flask to $70^{\circ}C$ for twenty minutes caused all color to disappear. Following the same separation techniques that produced the other two samples of ten millimeters pressure in a volume of 500 milliliters, a pressure of 18 millimeters of B_2H_5Br was obtained. After checking the spectrum of the third sample with that of the previous two, the three samples were combined. The reaction vessel was warmed at $70^{\circ}C$ to speed the kinetics of the reaction back toward equilibrium during the time between separations of the B_2H_5Br from the equilibrium mixture. Three more fractions of total pressure of 36 millimeters in a 500 milliliter volume were separated from the mixture. In all, a total of 74 millimeters pressure of B_2H_5Br was collected in a 500 milliliter volume. This quantity was ample for checking vapor pressure, and the resulting vapor pressure of 42 mm at $-44^{\circ}C$ agreed exactly with that found by Schlesinger and Burg /10/ and predicted by Stock. /9/ Another vapor pressure check gave a pressure of 95 mm at $-30^{\circ}C$ and also agreed exactly with Stock's value./9/

4. Infrared Spectrum of B_2H_5Br.

The infrared absorption spectrum was measured over the range 250 -- 4000 cm^1 by means of a Perkin - Elmer Model 221 spectro-photometer equipped with CsBr and NaCl prism-grating interchanges. The instrument was equipped with a housing so that it could be swept out with dry nitrogen. In this way the effect of water vapor absorption on the spectra was reduced to a minimum. In the low frequency region (250 -- 650 cm^{-1}), the CsBr prism was used, while the NaCl prism was used for the higher region. The resolution achieved was approximately uniform throughout the spectrum at about three cm^{-1}. The band maxima were measured with a precision of about three cm^{-1}. The gas absorption cells used were two cells ten cm in length with NaCl windows on one and CsBr windows on the other. Another five cm long micro gas cell equipped with IR-tran windows was used to resolve some weak bands.

The stability of the B_2H_5Br in the gas phase at room temperature was such that products of dissociation were noticeable as shoulders or small pips in the infrared spectrum after about thirty minutes. (See Fig. 3) Consequently, each gas phase spectrum required fresh separation of B_2H_5Br from its dissociation products. The change in the spectrum corresponding to the formation of B_2H_6 and BBr_3, the dissociation appeared to follow that reported by Schlesinger and Burg: /10/

$$6 \ B_2H_5Br = 5B_2H_6 + 2BBr_3$$

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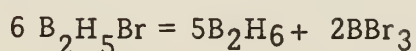
The solid B_2H_5Br spectrum was obtained from a film of B_2H_5Br frozen onto a CsBr window held at liquid air temperature by a brass holder being in intimate contact with both the window and the liquid air. The brass holder and its window were enclosed in an evacuated cell also equipped with CsBr windows. The results of the absorption measurements are presented in Figs. 3 through 8 and Table I.

TABLE I. Table of frequencies of B_2H_5Br bands and
their assignments

| Frequency, Cm^{-1} (Gas B_2H_5Br)	Intensity	Frequency Cm^{-1} (Solid B_2H_5Br)	Intensity	Assignment
2618	Strong			B–H asym.,
		2610	Strong	inphase
2603	Strong			(type B)
2580	Strong	2582	Strong	B–H asym., out of phase (type A)
2532	Strong			B–H sym.,
		2518	Strong	in phase
2516	Strong			type B
				B_2H_6
2496	Weak			impurity
		2440	Very Strong	?
2340	Very Weak	2358	Medium	?
		2333	Very Weak	?
		2282	Very Weak	?
1727	Weak	1727	Medium	B–H' asym., out of phase (type A)
1621	Medium	1620	Very Weak	B_2H_6 impurity
		1580	Very Strong	B–H' asym., in phase
1572	Very Strong			
		1554	Strong Shoulder	?
1540	Medium Shoulder			?
1488	Medium	1488	Very Strong	–B_2H_5 combination
		1445	Medium	?
1174	Weak			B_2H_6 impurity
1155	Weak			BH_2 deformation (?)
		1142	Very Strong	?
1064	Medium			BH_2
1049	Medium			deformation
		1042	Very Strong	?
		941	Weak	?
934	Weak			?
904	Weak	905	Strong	BH_2 wagging, out of plane
817	Weak	816	Strong	BH_2 wagging in plane
661	Strong	659	Strong	?
496	Strong	496	Strong	B–Br Stretch

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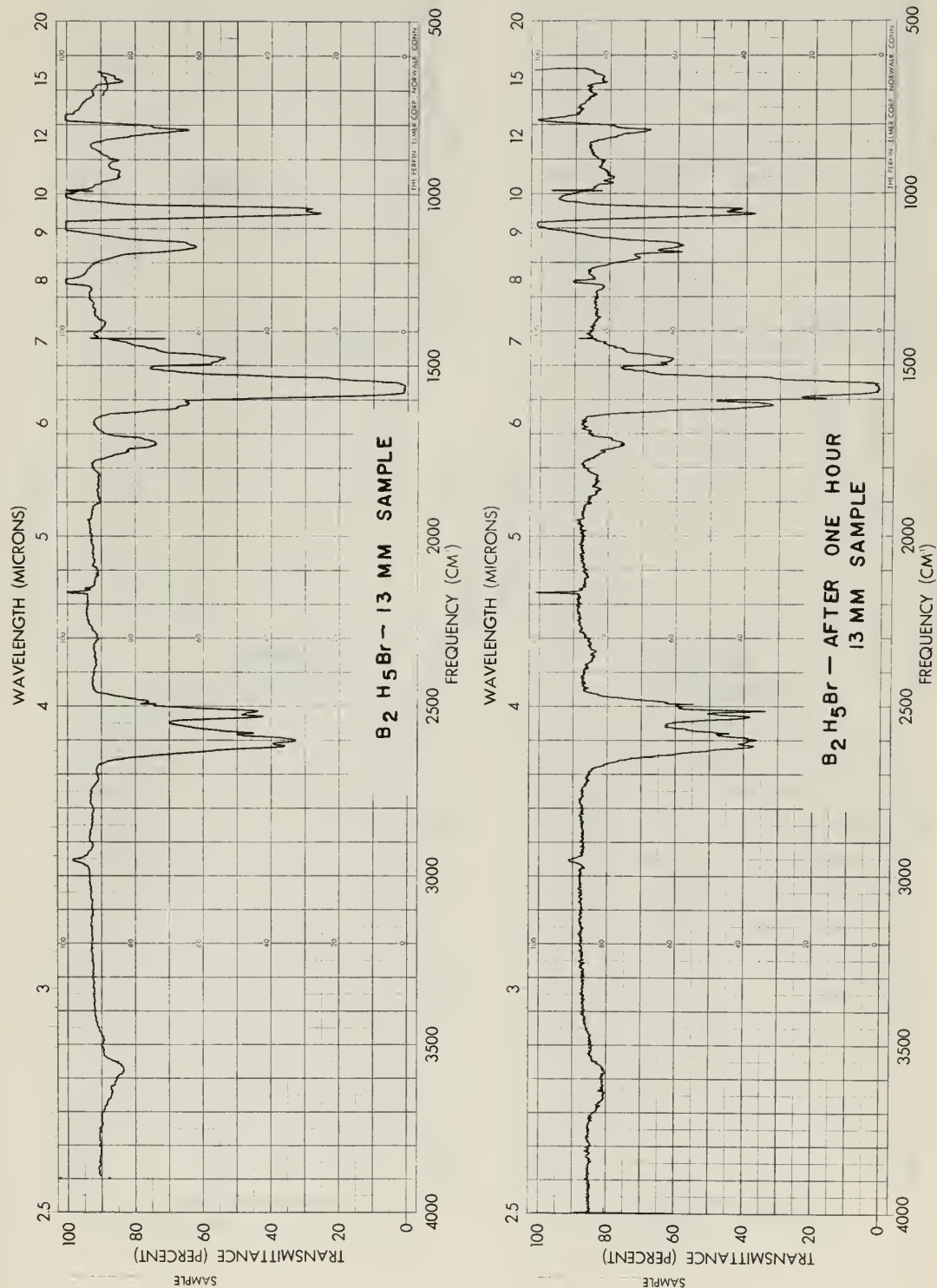
Fig. 3. Comparison of B_2H_5Br spectra when pure and after decomposing for an hour at room temperature.
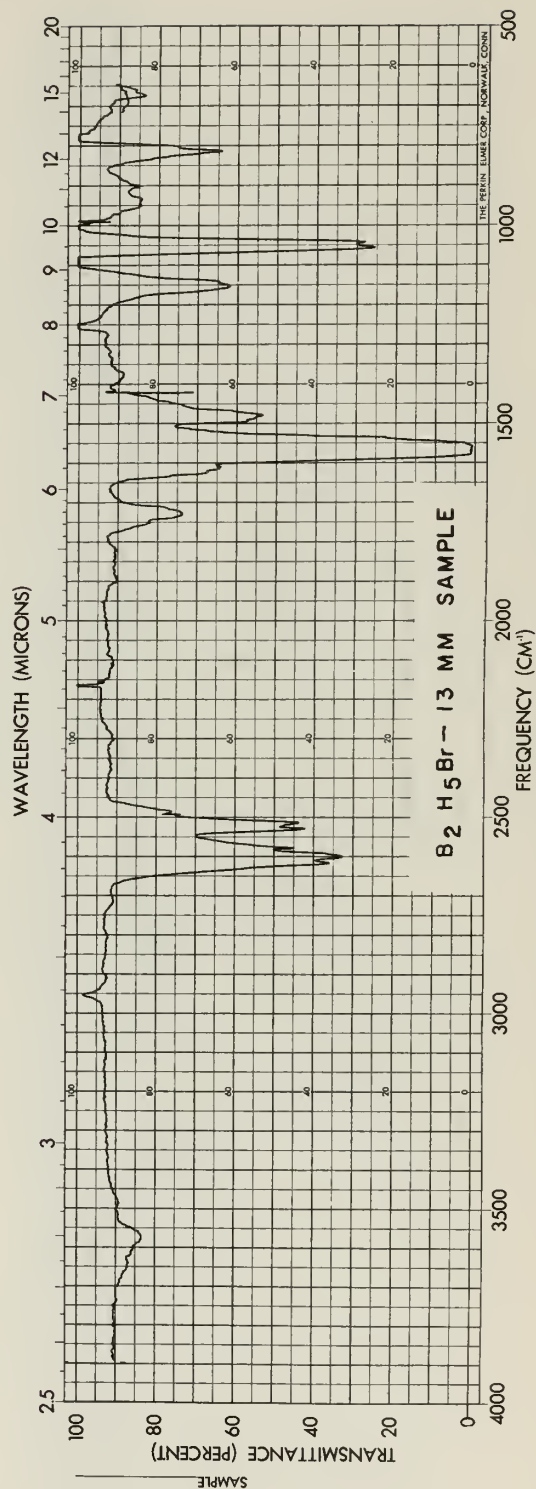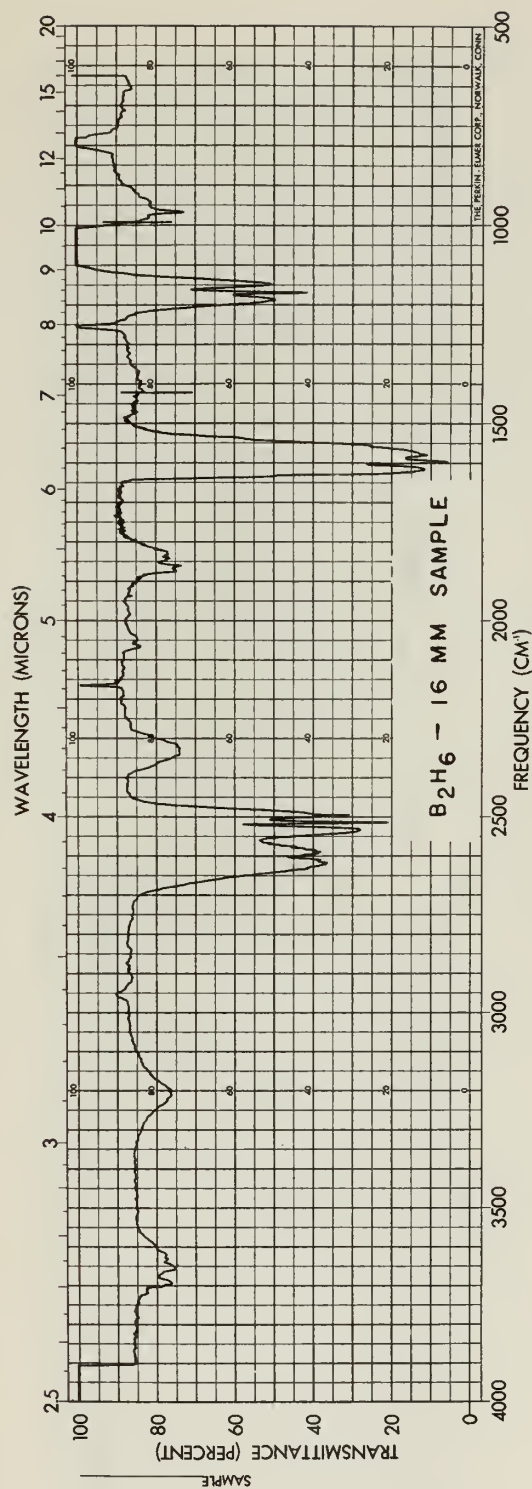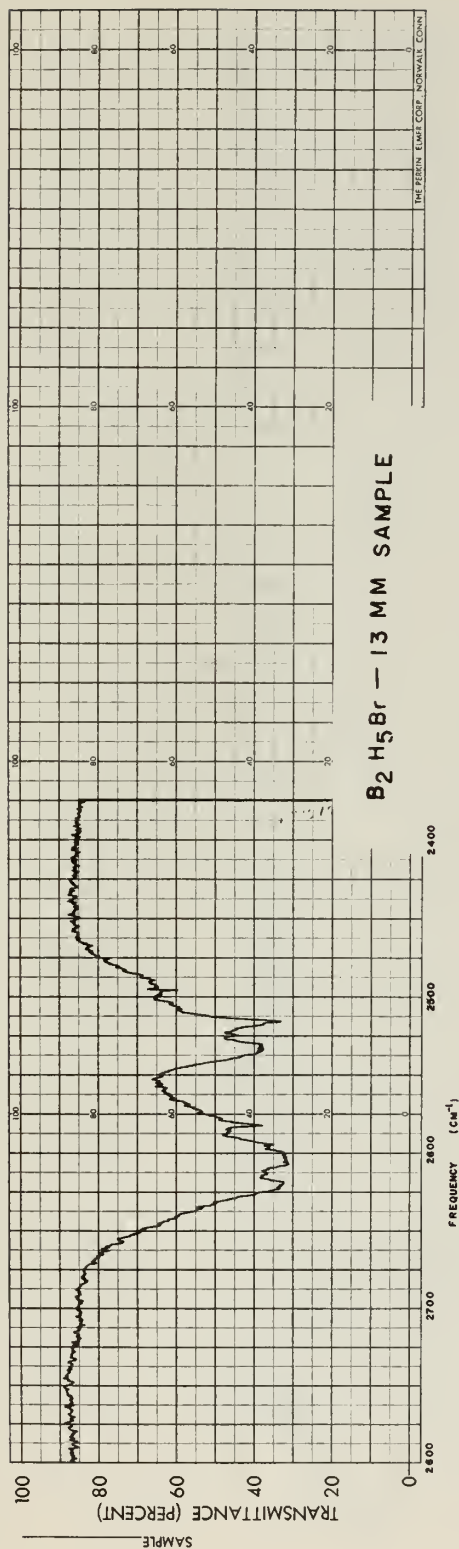
18

Fig. 4. Comparison of B_2H_6 and B_2H_5Br spectra.

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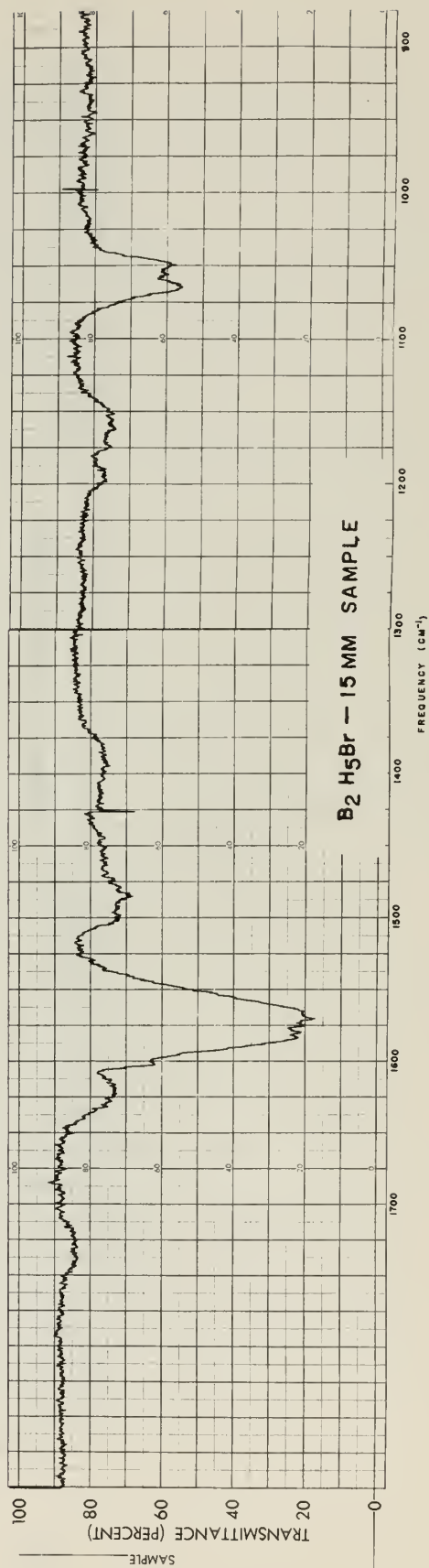
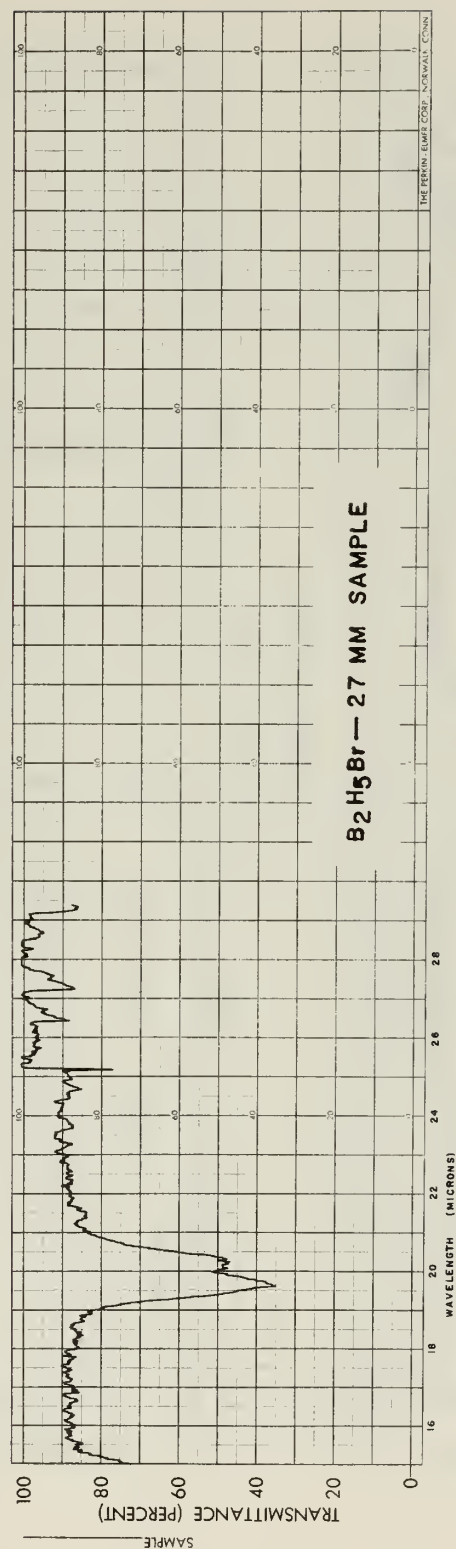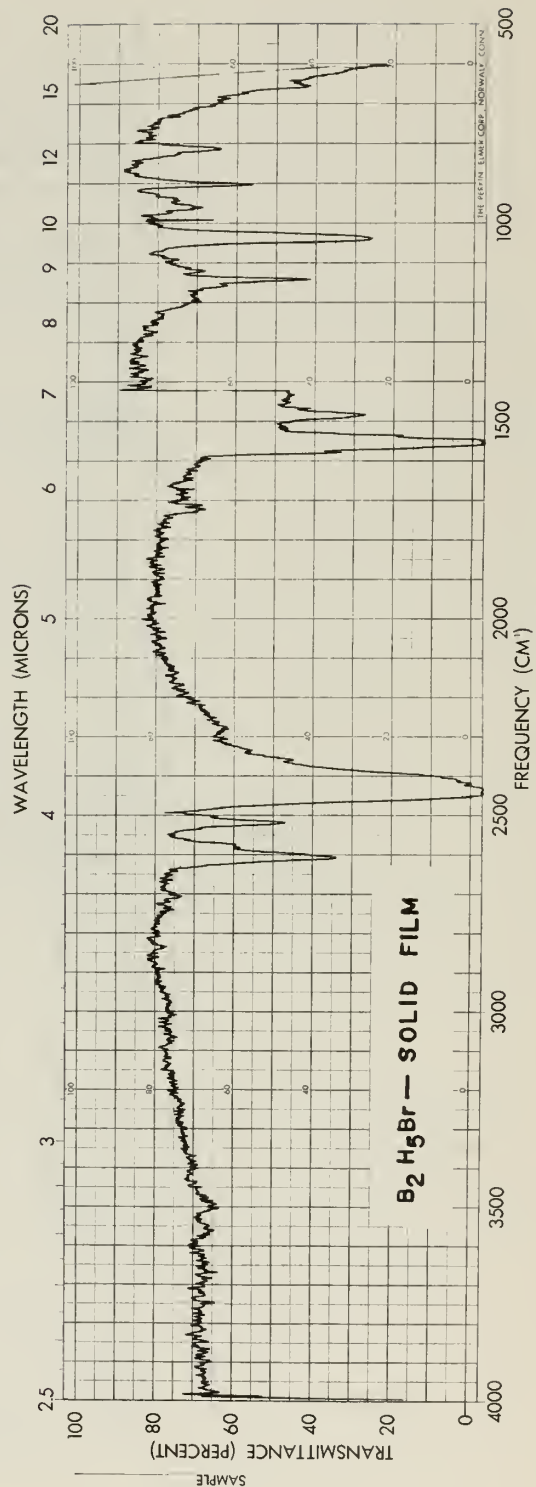Fig. 5. B_2H_5Br spectrum on expended scale.

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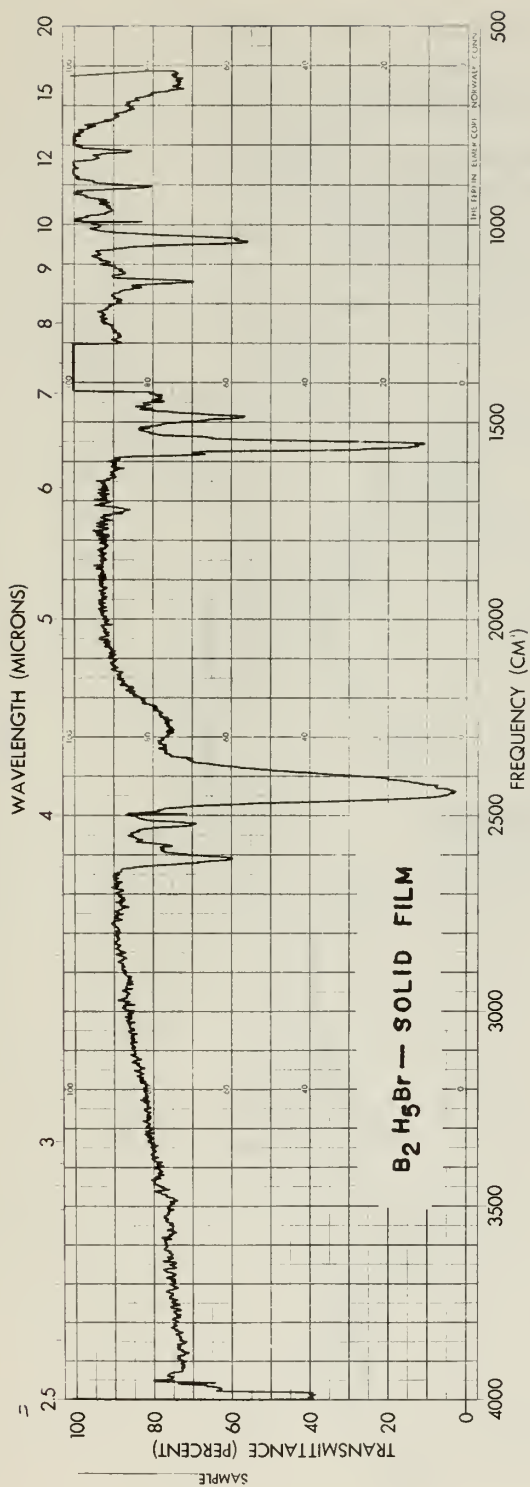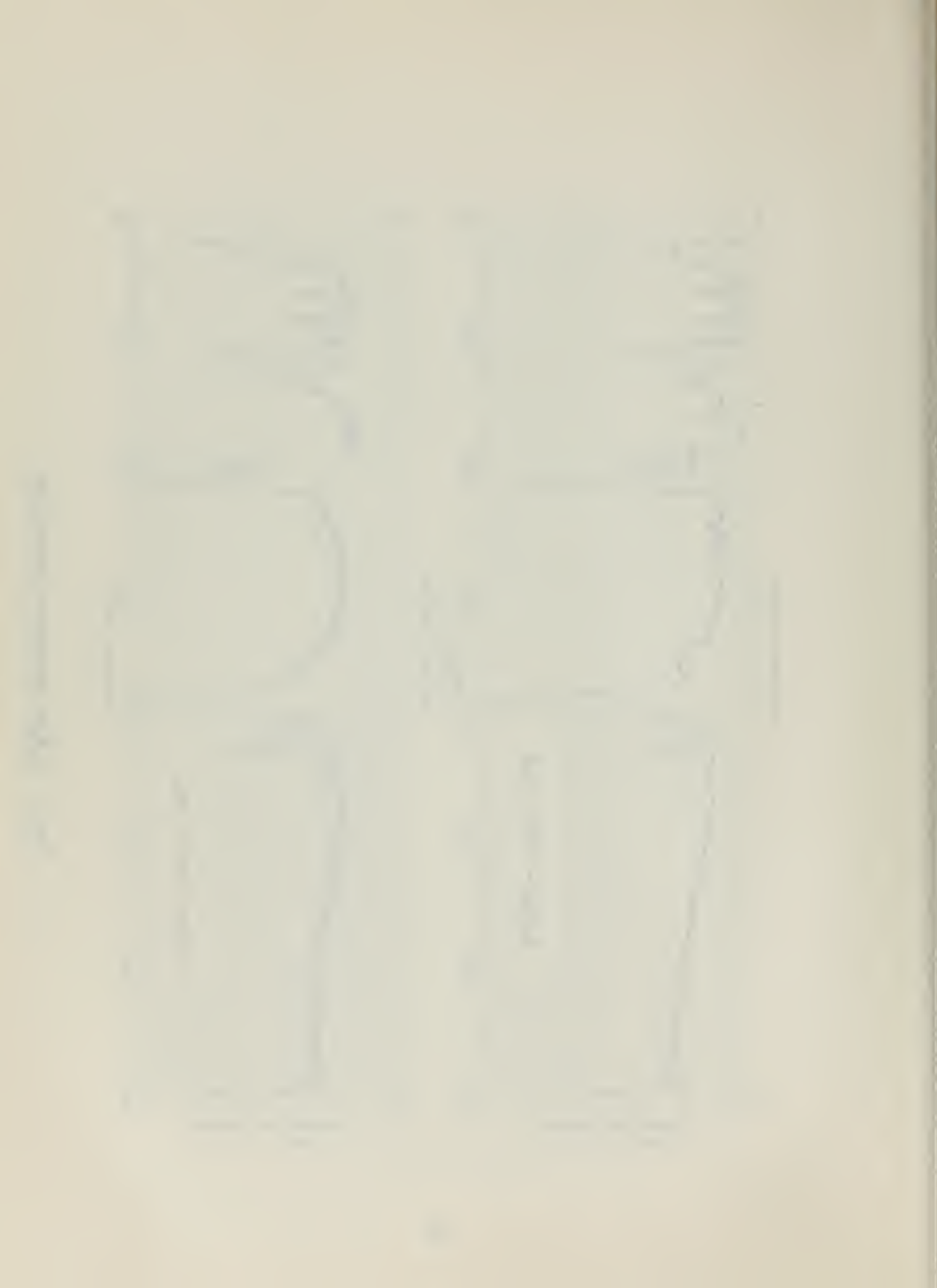Fig. 6. B_2H_5Br spectrum in cesium bromide region.
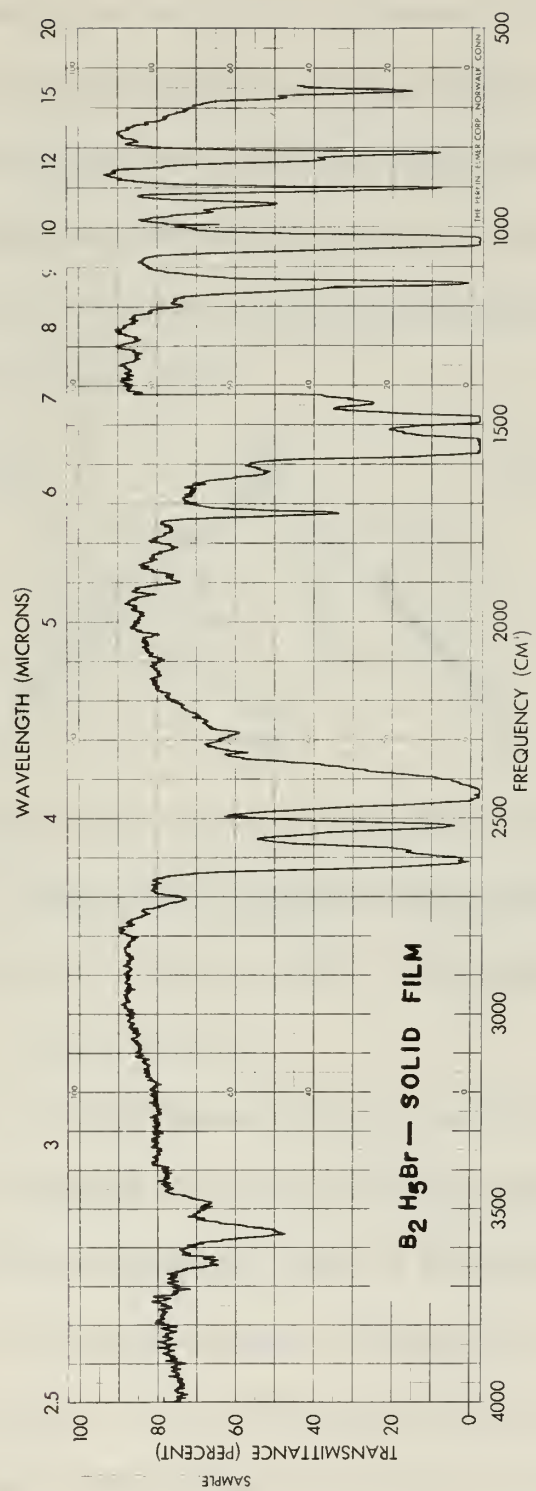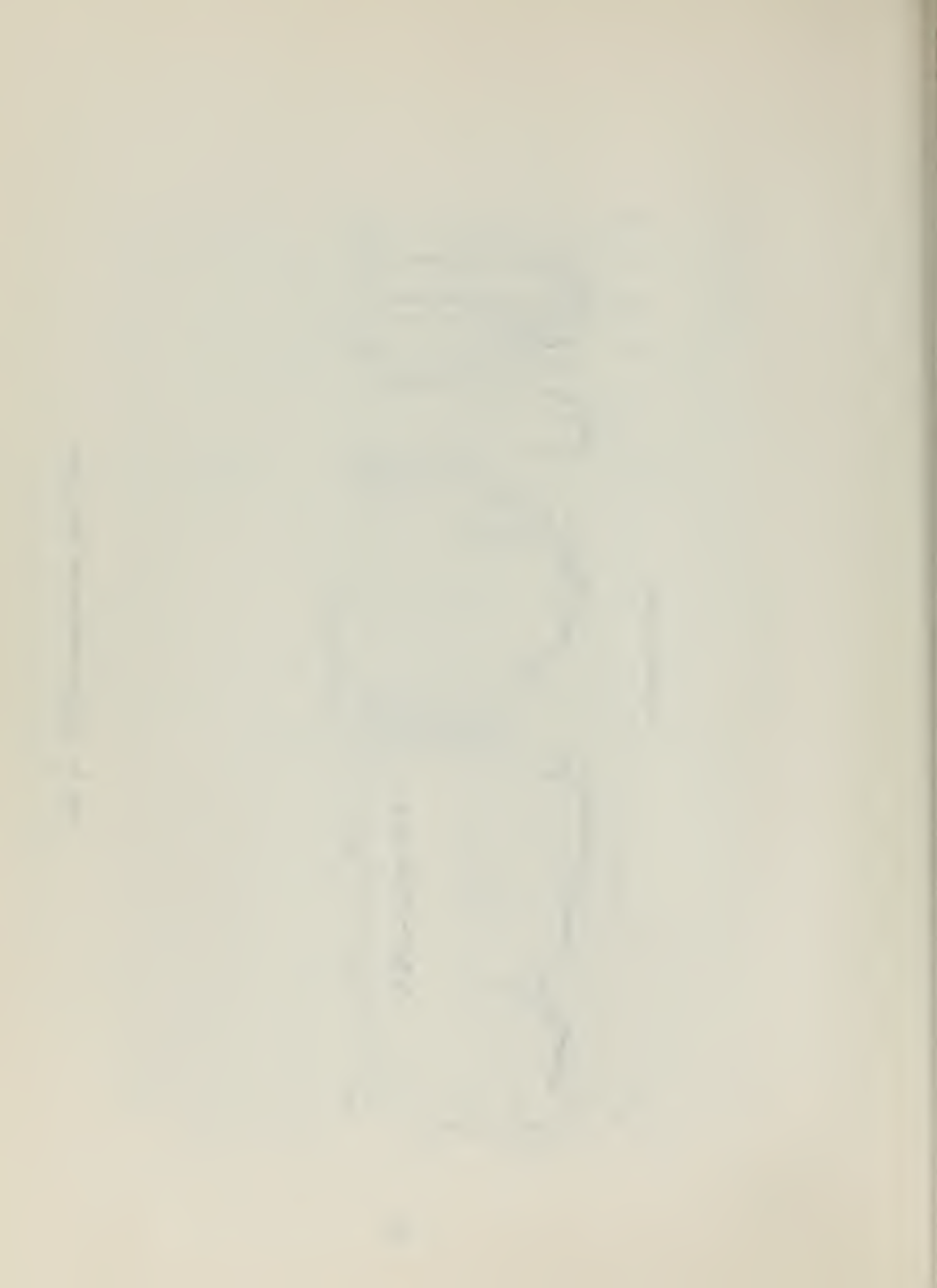
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Fig. 7. B_2H_5Br spectrum as solid film.

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Fig. 8. B_2H_5Br spectrum as solid film.

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III. INTERPRETATION OF INFRARED SPECTRUM OF B_2H_5Br

1. Symmetry of B_2H_5Br.

The presently accepted model of diborane /2/ is a bridge model in which two boron atoms and four terminal hydrogens lie in one plane while the same two boron atoms and the bridge hydrogens (designated H') lie in another plane perpendicular to the first. The configuration is shown below. /14/ The molecular dimensions were obtained by a careful electron diffraction study. /15/
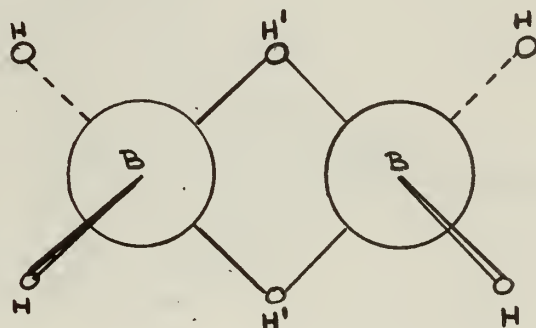
The hydrogen atoms with a ligancy of one, have a H-B distance of 1.187 $\pm$ 0.030^{O}A. The bridging hydrogen atoms with a ligancy of two, have a B-H distance of 1.334 $\pm$ 0.027^{O}A. The distance between the boron atoms is 1.770 $\pm$ 0.013^{O}A.

Since there are eight atoms in B_2H_6, the 3N less six fundamental vibrations total 18 and are numbered according to Bell and Longuet-Higgins, /12/ and are illustrated in Fig. 9 and described in Table II.

Hedburg, Jones and Schomaker /16/ report the structure of bromodiborane, B_2H_5Br, as essentially identical with that of diborane, except that a bromine atom replaces one of the non-bridging hydrogen atoms. Therefore, the symmetry of B_2H_5Br is reduced to one plane

| No.	Description	B_2H_5Br Species	Band Type
1	B-H sym., in phase	A'	AB
2	B-H' sym., in phase (breathing)	A'	AB
3	HBH in phase	A'	AB
4	B-B (slight B-H' stretch)	A'	AB
5	BH_2 twisting, opposite direct.	A''	C
6	B-H' asym., out of phase	A''	C
7	BH_2 wagging (into-with out-of-plane)	A''	C
8	B-H asym., in phase	A'	AB
9	BH_2 rocking ( )	A'	AB
10	BH'B (4th power)	A'	AB
11	B-H asym., out of phase	A'	AB
12	BH_2 rocking ( )	A'	AB
13	B-H' sym., out of phase	A''	C
14	BH_2 wagging (both into plane)	A''	C
15	BH_2 twisting same dir. (with motion of H')	A''	C
16	B-H sym., out of phase	A'	AB
17	B-H' asym., in phase	A'	AB
18	HBH out of phase	A'	AB
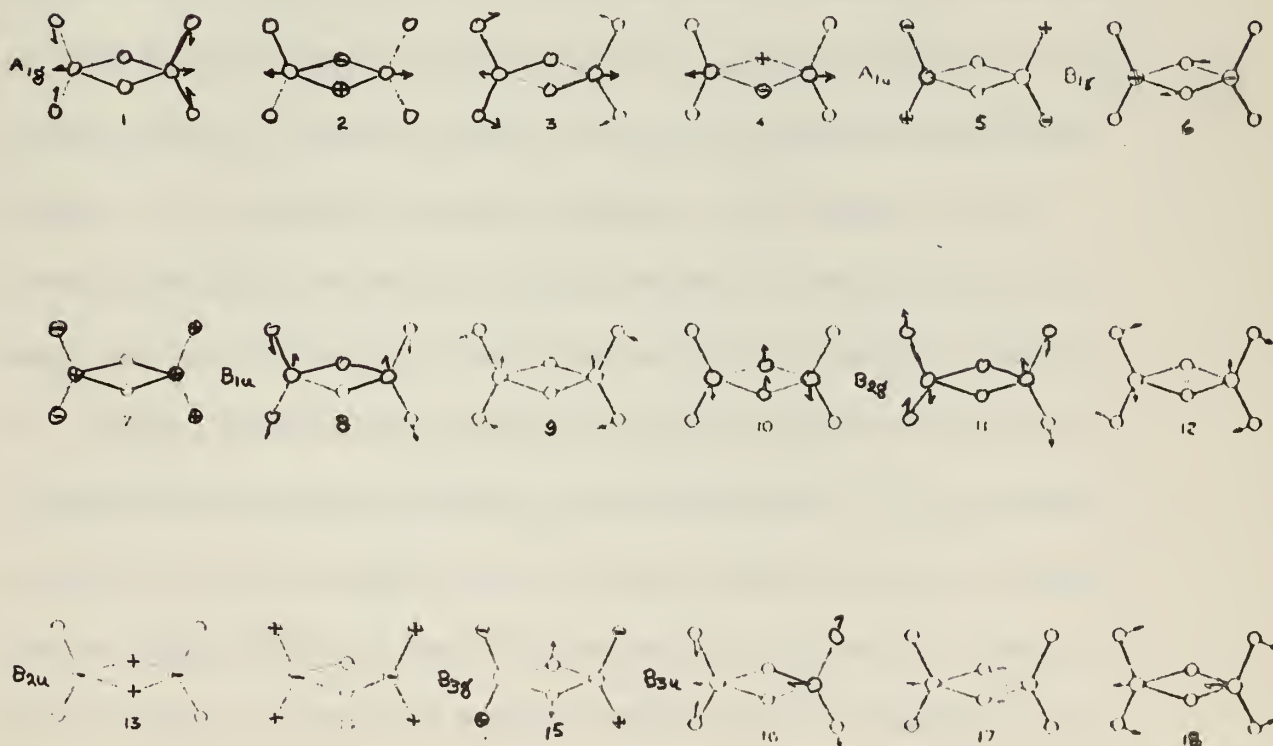
FIG.9 The character of the normal vibrations of "bridge" diborane.
After Bell and Longuet-Higgins.

(designated as symmetry point group C_s by Herzberg /13/) passing

through the bromine, the two boron atoms and the remaining terminal

hydrogens but passing perpendicular to the plane through the bridging

hydrogens. There are only two vibrational species possible. Vibra-

tions causing change of dipole moment within the plane of symmetry

are species A', and vibrations causing dipole changes out of the plane

are species A''. /13/ All 18 fundamental vibrations for B_2H_5Br are

infrared active. The 18 fundamental vibrations are composed of 12A'

species and 6A'' species. The symmetry relations for B_2H_5Br are also

summarized in Table II.

There are three band types to be expected in the B_2H_5Br spectrum.

Band type A refers to an absorption band in which there is a sharp center,

Q branch, flanked by the nearly as intense P and R rotational envelopes.

B-type bands refer to bands in which the center Q branch is absent and

only the flanking P and R branches remain. Band type C refers to a band

in which there is a sharp Q branch but no P or R branches are evident.

B_2H_5Br is an asymmetric top type molecule, and change of dipole

moment parallel to the axis of smallest moment of inertia, the minor

axis, and in the plane of symmetry produces A-type bands of species

A'. Dipole moment changes perpendicular to the minor axis and in the

symmetry plane yield B-type bands, also of species A'. Out of plane

vibrations producing dipole moment change parallel to the line through

the two bridge hydrogens yield C-type bands of species A''. Some of

the in-plane, A', vibrations actually exhibit hybrid AB character. /5/

2.   Frequency Assignments.

The spectrum of B_2H_5Br can best be analyzed by examining a small

frequency range at a time utilizing the assignments given for diborane

by Lord and Nielsen /1/ and correlating the expected shifts due to the

terminal bromine with the shifts reported for B_2H_5D and $B_2H_5CH_3$. /5,6/

See Fig. 10 for a pictorial illustration of the corellation.

In diborane, the B-H (terminal) stretching vibrations

(ν_1, ν_8, ν_{11}, ν_{16} in Fig.9) are in the 2500-2600 cm^{-1} region.

Terminally substituted monodeuterodiborane and methyldiborane also

show B-H stretch frequencies in this region. The asymmetrical stretch

frequencies are higher than the symmetric and are located at 2610 cm^{-1}

for the in phase (ν_8) vibration and at 2580 cm^{-1} for the out of phase

(ν_{11}) vibration. The lower frequency symmetrical stretch band is

found at 2520 cm^{-1} in B_2H_5Br.

The B-H' stretching frequencies (ν_6 and ν_{17}) are found in the

1750 to 1550 cm^{-1} region with the strongest band found in the region

corresponding to the asymmetric, in phase, ν_{17} in diborane. Thus

1572 cm^{-1} is assigned to the asymmetric in phase B-H' stretch, and

1730 cm^{-1} corresponds to the asymmetric out of phase B-H' stretch.

The fairly intense BH_2 deformation bands reported at about

1150 cm^{-1} for $CH_3B_2H_5$ /5/ appear shifted to the lower frequency of

about 1050 cm^{-1} for B_2H_5Br. However, one apparent A-type band of

medium intensity still remains at 1155 cm^{-1} and probably corresponds

to one of the BH_2 deformation bands that did not shift appreciably.

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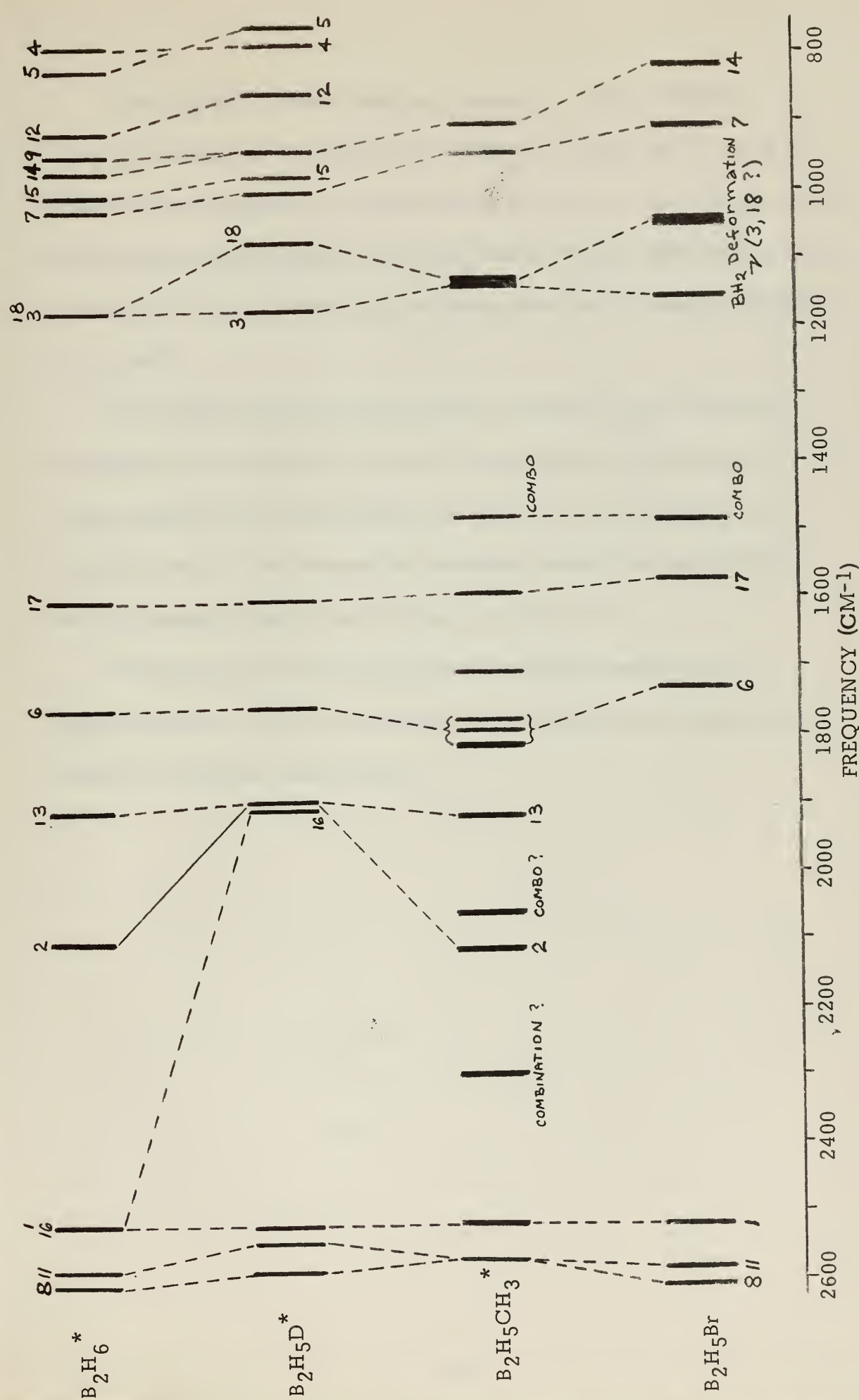
Fig. 10. Correlation of Frequencies for Terminally Substituted Diborane
* Previously assigned by Lehmann, Ditter and Shapiro /5,6/

The BH_2 out of plane wagging frequency, corresponding to v_7 in B_2H_6, appears in the region from 1000 cm^{-1} to 900 cm^{-1}. It is a sharp C-type band of low intensity found at 904 cm^{-1} for B_2H_5Br. The BH_2 in plane wagging band, corresponding to v_{14} in diborane, is found at a slightly lower frequency as another sharp band of medium intensity at 817 cm^{-1}.

Two other prominent bands stand out in the B_2H_5Br spectrum. The fairly intense band at 1488 cm^{-1} corresponds well with the $-B_2H_5$ combination band assigned as 1481 cm^{-1} for $CH_3B_2H_5$ /5/. The other band is the intense low frequency absorption expected for the B-Br stretch vibration and is found at 496 cm^{-1}.

While there are other unassigned absorption peaks in the B_2H_5Br spectrum, further correlation with $CH_3B_2H_5$ and B_2H_5D fails to yield any other firm assignments.

IV. DISCUSSION OF RESULTS

All the band assignments have been made using the spectrum of B_2H_5Br in the gas phase. The spectrum of B_2H_5Br in the solid phase is included for completeness, and it was quite useful in helping to determine whether a particular band was A-type or B-type. Although the Q branch is missing in the B-type band of a gas, the solid spectrum yields a simple peak at the vibrational frequency. Therefore, if there was little or no shift in frequency for a particular band when going from the gas phase to the solid phase, the type band was easily distinguishable. However, some of the bands do shift when in the solid phase as compared to the gas phase, and not all the bands could be determined as to type. Further infrared study of solid B_2H_5D and $CH_3B_2H_5$ and correlation in the solid state might allow some more firm band assignments for the $—B_2H_5$ fragment. No doubt some of the bands in the 2200 - 2450 cm^{-1} region of the solid spectrum could be assigned by a correlation of the solid spectra.

There is a large jump in the mass of the terminally substituted group when going from $—CH_3$ or $—CD_3$ to bromine, and the correlation of band assignments in the gas phase is not completely straightforward throughout the spectrum. The chlorodiborane spectrum would be especially useful in completing the correlation since it is of inter-mediate mass relative to the methyl and bromo substituted diborane; however, the greater electronegativity of the chlorine would complicate

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the correlation somewhat. Still the usefulness of an absorption

spectrum of chlorodiborane warrants another attempt at its preparation.

The attempts at preparing chlorodiborane for IR study in this

work were limited to mixing B_2H_6 and BCl_3 (or HCl) at a total pressure

of about one half an atmosphere. Preparation using the same techniques

only pressures of at least an atmosphere might be more fruitful. Although

the hope of separating the B_2H_5Cl from its dissociation and equilibrium

compounds is remote, compensation for the B_2H_6 spectrum could be

accomplished readily by placing B_2H_6 of near equivalent absorption

strength in the reference beam of the spectrometer. The interference

with the expected B_2H_5Cl spectrum due to the spectra of HCl and

BCl_3 would be minimal, and compensation for the B_2H_6 alone should

permit resolution of the B_2H_5Cl bands.

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